A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

NeoBiota 93: 225–244 (2024)
DOI: 10.3897/neobiota.93.105200

Project Description

LIFE PREDATOR: Prevent, detect, combat the spread of *Silurus glanis* in south European lakes to protect biodiversity

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Abstract

The management of Invasive Alien Species (IAS) is often hindered by ecological, social and economic factors, resulting in inadequate biodiversity protection and inefficient use of public money. A clear example of such inefficient management in aquatic ecosystems is the European catfish *Silurus glanis* L. in southern Europe. Native to central Eurasia, *S. glanis* is an emblematic and controversial freshwater fish, being the subject of extensive and profitable trophy angling in central Europe and of commercial fishing in eastern Europe. Concurrently, in western and southern Europe where it was introduced in the XIX century, *S. glanis* is considered a problematic invader. The lack of comprehensive information on *S. glanis* invasive populations has limited effective management, which is critical to successfully control the spread and minimize negative impacts on native ecosystems and species. LIFE PREDATOR, started in September 2022 with a budget of € 2.85 million and a consortium of six partners from three countries, aims at developing a multidisciplinary and transnational approach to control established populations of *S. glanis*, and prevent further spreading and future introductions in southern European lakes and reservoirs. The project will develop and test an early warning system based on eDNA and citizen science and identify the most effective and selective capture techniques to reduce the abundance of catfish, particularly in Natura 2000 lakes, actively involving anglers and professional fishermen on this. Massive raising awareness campaigns will be conducted targeting anglers but also the general public, and protocols and best practices will be transferred to management authorities. For the long-term sustainability of the project, a South European Management Group will be created. Additionally, in northern Italy, where the catfish invasion is more advanced, a local circular economy will be implemented, involving the increase in fishing pressure by encouraging catfish consumption as food.

Key words: Alien species management, angling, citizen science, eDNA, European catfish, freshwater fish, natural lakes, reservoirs

OPEN ACCESS

Academic editor: Nicola Smith
Received: 20 April 2023
Accepted: 15 November 2023
Published: 13 June 2024

Citation: De Santis V, Brignone S, Čech M, Eckert EM, Fontaneto D, Magalhães F, Martelo J, Ribeiro F, Vejřík L, Volta P (2024) LIFE PREDATOR: Prevent, detect, combat the spread of *Silurus glanis* in south European lakes to protect biodiversity. NeoBiota 93: 225–244. https://doi.org/10.3897/neobiota.93.105200

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Introduction

Invasive Alien Species (IAS) are internationally recognized as one of the major drivers of the current biodiversity crisis, particularly affecting fresh waters worldwide (e.g. Reid et al. 2019; Pyšek et al. 2020). IAS also seriously impact local and national economies with, for instance, the total global cost of aquatic IAS being

estimated in US$345 billion between 1971 and 2020 (Cuthbert et al. 2021). These costs arise not only from the damages caused by IAS but also from their management (Cuthbert et al. 2021; Haubrock et al. 2021), which includes prevention of introductions, control and eradication to mitigate and limit impacts, and education. IAS and the associated costs are continuously rising (Seebens et al. 2021; Cuthbert et al. 2022) and thus management has become imperative, although it is not always successful (Dana et al. 2019). Several ecological, economic and social factors influence the effectiveness of IAS management (Roberts et al. 2018), including the stage at which the management efforts are concentrated (pre-invasion *vs* post-invasion or early-stages *vs* later-stages) (Ahmed et al. 2022; Cuthbert et al. 2022), the information available on the biology and critical life stages of the IAS (Dana et al. 2019), and the public acceptance and awareness (Courchamp et al. 2017; Roberts et al. 2018).

The European catfish *Silurus glanis* L. is the largest freshwater fish in Europe. Native to eastern Europe and western Asia, it was introduced in western and southern Europe after the XIX century for enhancing recreational fishery, for aquaculture and, in a few cases, for biological control, and it established self-sustained populations in 13 European countries (Copp et al. 2009; Cucherousset et al. 2018; Froese and Pauly 2023). In southern Europe, it is considered a highly problematic IAS (Copp et al. 2009; Cucherousset et al. 2018), because of its top-predator position and ability to feed on a wide range of prey, its aggressive behaviour during the spawning period and high predation pressure on local fishes (Castaldelli et al. 2013; Vejřík et al. 2017a, b). The major ecological impacts associated with *S. glanis* invasion are (i) local extirpation or significant reduction in abundance and biomass of native fish (Castaldelli et al. 2013; Ferreira et al. 2019; Boulêtreau et al. 2021), (ii) potential alteration of energy fluxes between freshwater-marine habitats due to the predation on migratory species, such as European eel *Anguilla anguilla*, shads *Alosa* spp., salmon *Salmo salar* and sea lamprey *Petromyzon marinus* (Syväranta et al. 2010; Guillerault et al. 2017; Boulêtreau et al. 2018; Ferreira et al. 2019; Boulêtreau et al. 2021), and alteration of the nutrient cycles with increases in the amount of nitrogen in lakes and reservoirs due to its massive aggregations (Boulêtreau et al. 2011) (iii) potential competition with native predators, such as pike *Esox* spp. (Vejřík et al. 2017a) or *Perca fluviatilis* (Vejřík et al. 2017b) and (iv) potential introduction of new pathogens that adversely impact native fish (i.e. Spring Viraemia of Carp (SVC) and European Sheatfish Virus (ESV) (Reading et al. 2012; Rees 2020)).

Due to the increased awareness of the ecological impacts of *S. glanis*, project-supporting legislative tools started to consider this species as a priority. For instance, LIFE 15 GIE/IT/001039 ASAP, in accordance with Art. 12 Reg. EU N. 1143/2014, included *S. glanis* in the IAS national blacklist proposed for Italy although the blacklist has not yet been adopted by the Italian Ministry of the Environment, and LIFE GESTIRE2020 included it among the worst IAS in fresh waters. Moreover, to prevent this unwanted invader from expanding, some Italian administrative regions, such as Lombardy (LR 31/2008; RR 2/2018), Veneto (LR 04/1998), Emilia Romagna (DGR 1574-96) and Piedmont (LR 37/2006) have regulated *S. glanis* as prohibited, imposing a ban on both its introduction and release after capture. In Portugal, *S. glanis* has been included in the national IAS blacklist (Annex II) of the Decreto-Lei nr. 92/2019, forbidding its transport and detention, and within the legal framework of the Portuguese inland recreational

fisheries law (Decreto-Lei nr. 112/2017), anglers and professional fishermen are requested to euthanize this IAS once caught.

In addition to these measures, several local control campaigns have been carried out and are still ongoing, but the abundance of *S. glanis* remains unaffected (e.g., Milardi et al. 2022) and it keeps expanding its invasive range (e.g. De Santis and Volta 2021; Tutman et al. 2021; Mancini et al. 2022; Nyqvist et al. 2022; Gkenas et al. 2023). This is probably due to multiple reasons such as inadequate containment efforts, lack of awareness and compliance with current management policies by anglers, and lack of law enforcement. Non-effective management practices are influenced by the lack of quantitative information on most invasive populations (De Santis and Volta 2021), scarcity of information on habitat use and behaviour, and unsuitable capture techniques (Boulêtreau et al. 2016). New occurrences of *S. glanis* populations in southern Europe are the result of illegal introductions and releases in the region (Cucherousset et al. 2018; Lyach and Remr 2019; Vejřík et al. 2019a), which is likely linked to the appreciation of this species by trophy anglers (Boulêtreau and Santoul 2016). Some anglers may favour the expansion of nonnative species because they are unaware of the negative consequences their actions may have. Other anglers instead, do not share the conservatism view to halt the spread of nonnative species because they are motivated to catch large fishes and are convinced that the release of invasive fish such as *S. glanis* is not a problem and can constitute an additional resource (e.g., Nolan et al. 2019).

LIFE PREDATOR (http://lifepredator.eu/) was thus developed under these circumstances and represents the first project that will apply an integrated, comprehensive, and transnational approach to tackle the invasion of *S. glanis* in southern Europe.

Objectives

LIFE PREDATOR broadly aims at establishing and developing a feasible, reliable and effective system to prevent, detect, control and stop the spread of the invasive *S. glanis* in lakes and reservoirs of southern Europe. Specific objectives are to:

1. Prevent introduction and further spread by tackling the main vectors of introduction.
2. Develop, test, apply and disseminate an effective early detection system in lakes and reservoirs.
3. Develop, apply and disseminate effective capture techniques to be used in population control in lakes and reservoirs.
4. Improve the ecological status of lakes.
5. Develop a strategy for the long-term sustainability of the project goals.

Project area and partnership

The project will focus on lakes and reservoirs where *S. glanis* is thriving and management may be more feasible due to presence of barriers to natural dispersal. The project involves two European countries with different invasion histories (Italy and Portugal) and a country where the species is native (Czech Republic). In Italy, the first self-established population of *S. glanis* was detected in the 1960s and has since then spread in all northern and central major basins and in some southern large basins (De Santis and Volta 2021), taking advantage of environmental deg-

radation (Capra et al. 2018) and climate change (Britton et al. 2010). In Portugal, it probably arrived at the turn of the century (2006/2008) (Gkenas et al. 2015) invading the Tagus basin and, more recently, it has arrived in the Douro River from Spanish populations (Martelo et al. 2021; Gkenas et al. 2023). In Czech Republic, *S. glanis* is native and highly appreciated by anglers, with most populations under fishing regulation to ensure sustainability, which involve for instance: a minimum catch-allowed length set at 70 cm, fishing bans from 1 January to 15 June and bag limits of two individuals per day per angler (CAU 2023). The species is also used (and heavily stocked indeed) for biomanipulation purposes in case of i) water supply reservoirs and ii) newly created open cast mine lakes designated for recreational purposes to reduce the biomass of main zooplanktivorous fish species (Vejřík et al. 2017b, 2019a).

A total of 50 lakes and reservoirs (23 lakes in northern Italy, 25 reservoirs in Portugal and 2 reservoirs in Czech Republic), with different morphologies (depth and size), stages of colonization, and abundances of *S. glanis* will be targeted, including some where the species has not yet been reported but will likely be present in the near future. These lakes and reservoirs (Fig. 1, Suppl. material 1) will include:

- Italian large and deep lakes where the species is established.
- Italian small and shallow lakes where the species is established.
- Italian small and deep lakes where the species is established.
- Italian small and shallow lakes where the species has not been reported.
- Italian small and deep lakes where the species has not been reported.
- Portuguese large reservoirs in the Tagus River basin where the species is established.
- Portuguese small reservoirs in the Tagus River basin where the species is established.
- Portuguese small and large reservoirs where the species has not been reported in the Tagus, Douro and Guadiana River basins.
- Czech reservoirs in Vltava River where the species is native to be used as control (i.e., *S. glanis* here is native and no harm will be done to individuals caught in these reservoirs).

Six partners are involved: three scientific research entities (Water Research Institute of National Research Council of Italy; University of Lisbon; Biology Centre of the Czech Academy of Sciences) with solid scientific knowledge on fish ecology, fish invasions, and *S. glanis*; one private enterprise (GRAIA s.r.l.) with large experience on environmental management and communication; and two administrative entities (Città Metropolitana di Torino; Ente di gestione delle aree protette delle Alpi Cozie) responsible for the management of some of the lakes targeted by the project and sites included in the Natura 2000 European network (Directive 92/43 EEC).

Structure and approaches of the project

The project is structured in 7 multidisciplinary work packages (WPs 2 to 8) informing and complementing each other, plus WP1 dedicated to the project coordination and management (Fig. 2). A brief description of each WP is provided below.

Figure 1. Location and sample pictures of lakes and reservoirs targeted by LIFE PREDATOR **A** distribution of the 50 lakes and reservoirs targeted by the project **B** Lake Maggiore (Italy) provided by Gabriele Tartari (Water Research Institute-National Research Council) **C** Avigliana Grande and Piccolo lakes provided by Bruno Aimone (Ente di gestione delle aree protette delle Alpi Cozie) **D** Lake Campagna (Italy) provided by Alessandra Pucci (Città Metropolitana di Torino) **E** Cedillo Reservoir (Spain-Portugal) provided by Filipe Ribeiro (co-author) **F** Belver Reservoir (Portugal) provided by Lukáš Vejřík (co-author) **G** Žlutice Rervoir (Czech Republic) provided by Martin Čech (co-author) **H** Římov Reservoir (Czech Republic) provided by Lukáš Vejřík (co-author).

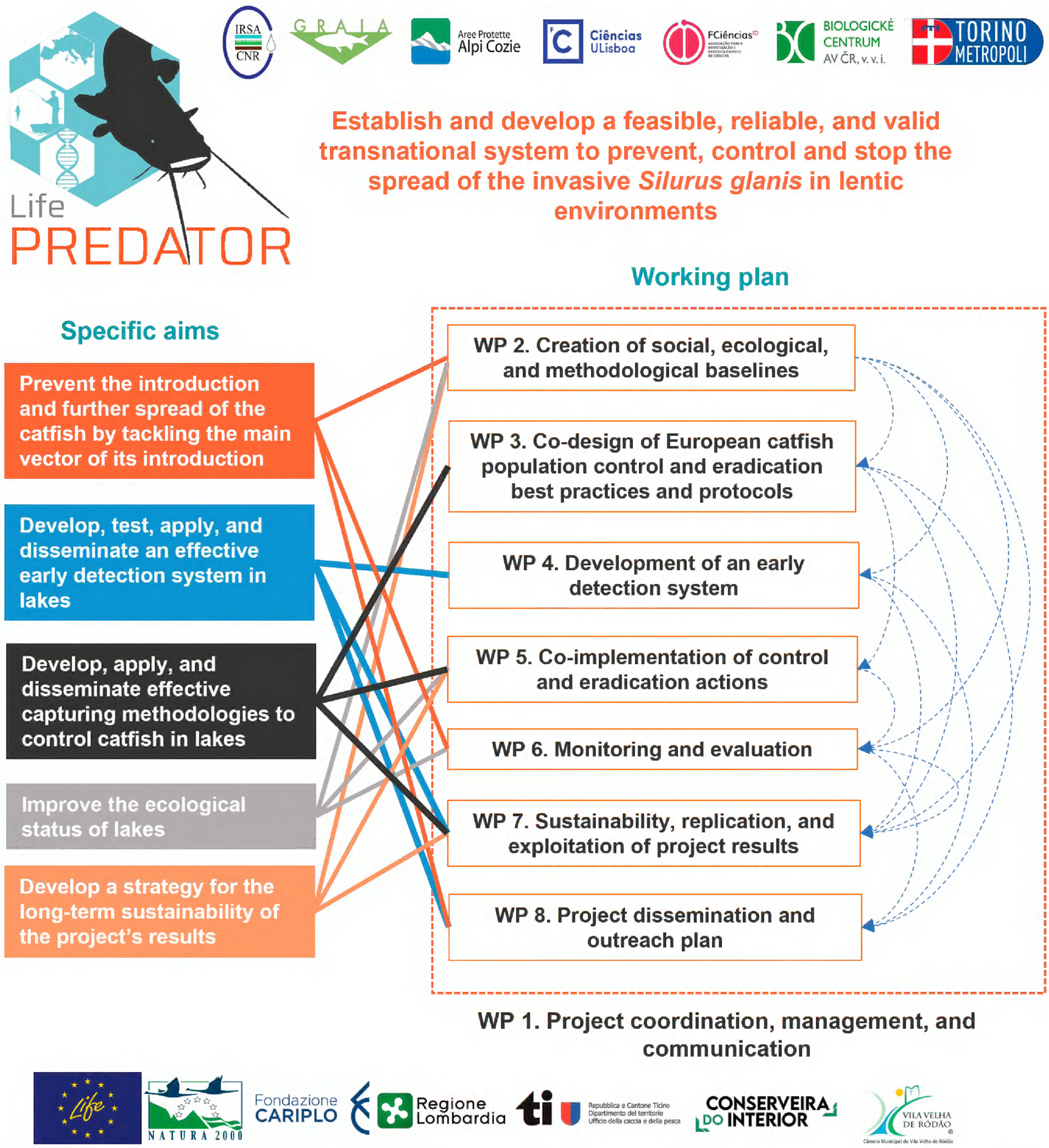
Life
PREDATOR
Establish and develop a feasible, reliable, and valid transnational system to prevent, control and stop the spread of the invasive *Silurus glanis* in lentic environments
Working plan
Specific aims
Prevent the introduction and further spread of the catfish by tackling the main vector of its introduction
Develop, test, apply, and disseminate an effective early detection system in lakes
Develop, apply, and disseminate effective capturing methodologies to control catfish in lakes
Improve the ecological status of lakes
Develop a strategy for the long-term sustainability of the project's results
WP 2. Creation of social, ecological, and methodological baselines
WP 3. Co-design of European catfish population control and eradication best practices and protocols
WP 4. Development of an early detection system
WP 5. Co-implementation of control and eradication actions
WP 6. Monitoring and evaluation
WP 7. Sustainability, replication, and exploitation of project results
WP 8. Project dissemination and outreach plan
WP 1. Project coordination, management, and communication

Figure 2. Conceptual structure of LIFE PREDATOR. Connections between the specific aims of the project and the work packages (WPs) are displayed, as well as the interactions among WPs. The project logo is displayed at the top left beside the logos of project beneficiaries. The logos of financers are at the bottom.

WP1. Project coordination, management, and communication

This WP concerns the overall coordination and management of the project and aims to i) guarantee the administrative execution of the project, through the preparation of the grant agreement, the establishment of the steering committee and the management team, the definition of the internal management hierarchy, and the request of authorizations needed for the execution of the project activities; ii) ensure and facilitate exchanges and interactions between the project consortium

and the stakeholders through the development of a communication and outreach plan; iii) monitor the project progresses guaranteeing the timely accomplishment of milestones and production of deliverables.

WP2. Creation of social, ecological, and methodological baselines

Given the multiple social influences on *S. glanis* spread and management and the scarcity of ecological information on the species in lakes and reservoirs, the aim of this WP is to gather and evaluate social and ecological information for developing a baseline to understand the socio-ecological systems where catfish is or can be established.

Because stakeholder engagement and perception are critical aspects in IAS management (Crowley et al. 2017a; Shackleton et al. 2019), the potential interested stakeholders will be screened and identified and their knowledge, perception and interests in *S. glanis* invasion will be assessed through structured interviews. Selected key stakeholders (e.g., fishermen and anglers) will then be integrated in local alliance groups and divided into operational, warning and evaluation teams. These teams will actively contribute, respectively to i) test catfish capture techniques (WP3) and implement control and eradication campaigns (WP5), ii) test the early detection of catfish (WP4), and iii) test the evaluation of best methods for processing catfish for human consumption (WP7).

To increase the ecological knowledge on *S. glanis*, species occurrence and habitat use will be modelled in eight selected lakes and reservoirs, in relation to biotic (e.g., prey availability and catfish density) and abiotic (e.g., nutrient concentration, water temperature) conditions and human use, between seasons (late spring and late autumn) and over the diel cycle. Specifically, it will be analysed whether there is a recurrent winter aggregation pattern as recently found in a shallow lake in southern France (Westrelin et al. 2023). This information is crucial to inform where and when to test capture methodologies (WP3), and to concentrate control and eradication efforts (WP5). In addition, this will help predict the likely suitable habitats in uninvaded lakes and reservoirs where early detection monitoring should be focused (WP4).

The models will be built on data obtained with multiple methodologies contingent on the characteristics (e.g., size, depth, bathymetry) of the selected lakes and reservoirs. Underwater drones, echosounders and imagine sonars will be used to characterize habitats and acoustic telemetry to monitor fish behaviour and movement and complemented by direct observations through scuba diving and questionnaires to lakes and reservoirs users (e.g., fishermen, anglers, scuba divers). Models of habitat use for each lake and reservoir typology will be used to further estimate the invasion risk of the remaining 40 targeted lakes and reservoirs based on their abiotic characteristics and human uses.

Finally, since information on population size and structure is scarce (Vejřík et al. 2019a; De Santis and Volta 2021) and often not updated, quantitative sampling will be conducted to determine fish abundance in the 10 lakes and reservoirs where control and eradication actions will be performed (WP5). These data will also serve as baselines for monitoring of ecological quality of the lakes using fish as indicators (WP6). The quantitative sampling will be extended to eight additional lakes and reservoirs where no eradication nor control actions will be undertaken, following a Before-After-Control-Impact (BACI) monitoring approach (Smith 2002).

WP3. Co-design of European catfish population control and eradication best practices and protocols

Compared to other fish, *S. glanis* is inherently difficult to catch, particularly via standard sampling techniques (e.g., Vejřík et al. 2019a; Vejřík et al. under review), which strongly limits the efficiency of current control and eradication campaigns. Thus, this WP seeks to define effective sampling protocols for different lake and reservoirs typologies (i.e., large, and small lakes and large and small reservoirs). The protocols will primarily provide information on best timing, most efficient gears and type of effort (e.g., see Vejřík et al. 2019a, b) and most suitable habitats for capturing catfish, considering cost efficiency ratios and selectivity of the techniques. Different gears will be tested, including electro fishing, gillnets, seine nets, longlines and spearfishing by scuba diving. Results of WP2 on habitat use of catfish will be essential for the identification of sites where efforts should be concentrated. Operational teams formed in WP2 will actively participate in these experimental campaigns.

WP4. Developing an early warning detection system for European catfish

After prevention, early detection critically determines the success of IAS eradication efforts (de Groot et al. 2020; Reaser et al. 2020). WP4 aims at developing a strategy for the early detection of *S. glanis* in lakes and reservoirs based on environmental DNA analysis (Taberlet et al. 2012) and citizen science (Silvertown 2009), two approaches that are currently recognized as highly effective for this purpose (e.g., Parrondo et al. 2018; Larson et al. 2020; van Rees et al. 2022).

For the eDNA detection of *S. glanis*, a quantitative real-time PCR (qPCR) assay will be developed, involving three steps: i) in-silico selection of primers for the specific amplification of a *S. glanis* marker gene, with subsequent ruling out of cross-amplification with non-target DNA of sympatric fishes (e.g., Roy et al. 2018); ii) experimental trials in tanks to test DNA shedding rate (e.g., Plough et al. 2021) at different *S. glanis* abundances and in the presence or absence of sympatric fish, and iii) test of the developed qPCR assay in water samples from 10 large and small lakes and reservoirs where *S. glanis* abundance is known from WP2, in three lakes where the species is absent, used as negative references (avoiding false positives) and in the two Czech reservoirs where the species is native to be used as positive references.

Once the eDNA assay is developed and validated, it will be implemented to track the occurrence and the relative abundance of *S. glanis* in Italian lakes where the species has not yet been reported (eight lakes), and where it was reported but not captured (six lakes) and in 21 Portuguese reservoirs in the Tagus, Douro and Guadiana rivers where it has not yet been reported. For lakes and reservoirs testing negative for the presence of the fish DNA, the eDNA survey will be repeated regularly while for those testing positive, it will be implemented as described below for citizen science records.

For the citizen science detection of *S. glanis*, warning teams composed by anglers, fishermen and other water body users (e.g., local diving clubs) formed in WP2 will register and report new potential records of catfish in lakes and reservoirs where the species has not yet been reported. These records will be validated with pictures or videos (e.g., Gago et al. 2016) and reported in social networks (i.e., BioDiversity4All/iNaturalist) and/or directly to the communication manager of the project.

Validated citizen science and positive eDNA records will be compiled, transferred and integrated into national (e.g., SNIPAD, Portuguese Information System on Freshwater Fishes), European (e.g., EASIN European Alien Species Information Network) and international databases (e.g., GRIIS Global Register of Introduced and Invasive Species), and transferred to the competent authorities (Management Authorities, i.e., Parks and Regions) that will manage catfish following the protocols established in the project (WP5).

WP5. Co-implementation of control and eradication actions

This WP involves the implementation of the best capture protocols identified in WP3 for each lake and reservoirs category. Specifically, systematic control campaigns will be carried out from the third (2024) to the fifth year (2026) of the project, in one large lake (Lake Maggiore, in five small, protected lakes included in the Natura 2000 network) in Italy and in two small and two large reservoirs across the Tagus River in Portugal (Suppl. material 1). Control and eradication campaigns will be performed by the operative team members with the help and under the coordination of the project beneficiaries. At the end of each campaign, catfish will be euthanized following the national procedures to reduce animal angst and suffering, weighed (body mass, kg) and measured (total length, cm) and properly disposed. In Lake Maggiore, disposal will include the donation of catfish to a technical high school for cooking trials and to a social restaurant where the fish will be cooked and sold at a fair price as described further in WP7.

Specifically, in Lake Maggiore, the second deepest (max depth = 370 m) and largest (surface = 210 km^2) perialpine lake in Italy, a reduction by 10% of the biomass of catfish is expected. This percentage is estimated to correspond to the removal of 39 tons of *S. glanis*, considering the annual professional fish harvest in the lake (De Santis and Volta 2021).

Eradication campaigns in the five small, protected Italian lakes (Suppl. material 1), aim at reducing the biomass of catfish by 90%. Assuming a removal rate of 60 kg catfish/sampling day – estimated based on previous projects carried out by the beneficiaries in L. Comabbio and on the yield of the professional fisherman who exercise here – this will translate into the removal of a total of 10,860 kg of *S. glanis,* distributed as follow: Comabbio 7,200 kg, Avigliana Grande 1,800 kg, Avigliana Piccolo 1,200 kg, Sirio 600 kg and Campagna 60 kg.

Control campaigns in Portuguese reservoirs are expected to reduce the biomass of catfish by 10% in two large reservoirs (Fratel and Cedillo) and by 50% in two small reservoirs (Meimoa and Belver). An average removal rate of 20 kg/fishermen/day is expected from previous knowledge available on *S. glanis* catch rate from these reservoirs. Considering the fishing efforts foreseen for each of the four reservoirs, this is estimated to translate into a total of 12,000 kg (12 tons), distributed in the following way: Meimoa 540 kg, Belver 1,200 kg, Fratel 4,200 kg, Cedillo 6,000 kg.

WP6. Monitoring and evaluation

This WP involves the monitoring of the project impacts in relation to the i) effectiveness in reducing *S. glanis* biomass in target lakes and reservoirs; ii) impacts on the biodiversity and fish assemblages; iii) impacts on ecosystem functions and services; iv) social perception of *S. glanis* invasion and management.

Effectiveness in reduction of catfish biomass in the 10 target lakes (WP5; Suppl. material 1) will be assessed replicating the quantitative fish sampling at the beginning of the project (WP2) and at its end, in 2026. Additionally, data gathered during fish sampling will be used to determine the Lake Fish Index (Volta and Oggioni 2010), the official Italian index used for the assessment of the ecological status of lakes according to the European Water Framework Directive (2000/60/EC).

Environmental DNA will complement quantitative fish sampling in assessing the effectiveness of control actions (using the qPCR assay developed in WP4) and evaluating the impacts on the ecological status of the lakes. This will be achieved via metabarcoding (i.e., the simultaneous analysis of DNA of multiple species at a given DNA region referred as a barcode e.g. Deiner et al. 2017) targeting the whole eukaryotic community. There is indeed increasing evidence on the utility and applicability of metabarcoding (Zou et al. 2020; Saenz-Agudelo et al. 2022; Takahashi et al. 2023), which soon may supplement traditional approaches for the evaluation of ecological quality in fresh waters (Pawlowski et al. 2018). Collection of water samples for both metabarcoding and qPCR will follow the BACI approach. For metabarcoding, the sequences obtained from the target DNA region (e.g., eukaryotic 18S rRNA), will be compared with sequences available in public databases (i.e., GenBank) for the Amplicon Sequence Variants (ASVs) identification and subsequent taxonomic attribution. Matches with an identity above 99% will be considered at species level while matches above 97% and 95% will be considered at genus and family level, respectively. In case of multiple best matches, the most recent common taxon will be assigned. The resulting groups will be used to estimate both alpha and beta diversity and will be tested for significant variations before and after eradication/control campaigns, between control and impact locations, and relative interactions.

Impacts of the project on lakes' functions will be derived from changes in the structure of the food webs. Food webs are complex networks of interspecific interactions and are therefore key structural components of ecosystems, which are strictly linked to their quality, function, and associated services (Thompson et al. 2012). Among other tools, analysis of stable isotopes of carbon and nitrogen (SIA) is widely used to assess food web structure, and quantify changes in trophic links over time and space (Layman et al. 2012). SIA will thus be used to quantify variations in the trophic structure of the lakes and reservoirs in which eradication and control actions are foreseen (WP5), following the BACI approach. Samples of primary producers (macrophyte, phytoplankton and particulate organic matter) and consumers of different trophic levels (from zooplankton and macroinvertebrates to fish) will be collected during the two campaigns primarily dedicated to quantitative fish sampling.

Strictly linked to ecosystem functioning are the ecosystem services, such as provisioning, regulation, and cultural services. Changes in ecosystem services (both gain and loss) are seldom evaluated in regard to IAS (Milanović et al. 2020), although they can play an important role in their management (Martinez-Cillero et al. 2019). The identification, characterization, and diagnosis of ecosystem services in lakes and reservoirs where removal of *S. glanis* is planned and in control ones, before and after the actions are taken, will be based on the Mapping and Assessing Ecosystems and their Services (MAES) framework (Maes et al. 2014) and will follow the Common International Classification of Ecosystem Services (CICES; https://cices.eu/). The process will involve the following procedures: i) gathering

and analysis of information on a) local biodiversity, b) uses and activities in lakes and reservoirs and surrounding landscapes, c) ecological integrity, d) pressures affecting ecosystem services condition and risk of degradation; e) environmental factors relevant to the characterization of the ecosystem services (e.g., climatic time-series, geology); ii) ecosystem service identification, assessment, mapping and diagnosis; iii) field trips for validation, identification of knowledge gaps and collection of additional information; iv) interviews with key stakeholders identified in WP2 to gather supplementary information; and v) development of a conceptual model for the conservation of ecosystem services in lake and reservoir networks.

Finally, this WP foresees the evaluation of the social impacts (perception and awareness) of the project given the importance of these factors for the success and long-term sustainability of the project (Crowley et al. 2017b). Three social groups will be targeted: schoolchildren, adults, and fishermen/anglers. The latter group has a crucial role for the objectives of the project since they are the main vector of *S. glanis* spread and introduction. Immediately before awareness events ("travelling exhibition") and educational activities foreseen in WP8 are undertaken, school children and adults will be interviewed, to evaluate their perception about topics such as invasive species, nature conservation, *S. glanis* and other freshwater fishes. For school children, interviews will be repeated at the end of the educational program and the changes in their perception will be assessed. For adults, emails and phone numbers will be collected and they will be interviewed again at the end of the project. Fishermen and anglers, will be identified in WP2 and asked to answer the semi-structured interviews planned in that task and their perception regarding capture methods and fishing and catfish impacts, will be further assessed through a similar structured interview at end of the project.

Moreover, the impacts of the project on the number of users that will benefit from food provision by social cooperatives (see WP7) will be monitored using as indicator the number of people eating catfish standardised for the number of catfish made available per year.

WP7. Sustainability, replication, and exploitation of project results

This WP aims at developing a multiple strategy to ensure the long-term self-sustainment, replication, and exploitation of the project results. Different activities are foreseen, the first of which being the creation of a local circular economy based on the consumption of *S. glanis* caught in northern Italian lakes, where the invasion is more advanced. Culinary consumption can be an effective method to increase the fishing pressure on aquatic IAS (e.g. Varble and Secchi 2013; Huth et al. 2016). However, the promotion of the use of IAS for human consumption comes with a risk to create a demand that could eventually lead to further voluntary introductions (e.g., Nuñez et al. 2012) and this should be kept under monitoring and avoided when other solutions are feasible. Nevertheless, this approach appears to be the most cost-effective and self-sustainable to maintain under control the impacts and abundance of invasive species once their populations have reached a point in which eradication is no longer feasible (e.g., Cerveira et al. 2022). In fact, this approach seems to be particularly suitable for a long-lasting and self-sustained management of *S. glanis* in large lakes, which otherwise would only be targeted by recreational anglers that sometimes fail their obligations and release the fish to water. Moreover, due to its fast growth particularly in the first year of life, *S. glanis*

rapidly reaches a predator safe size, and without or with much fewer natural predators, will continue to thrive and require continued investments for its control. The meat of *S. glanis* is not appreciated in Italy, and people refuse to consume it, lacking the knowledge and the tradition to consider this fish for feeding. The shape, the colour and the abundant mucus discourage it to be considered a palatable food. Therefore, fishermen working on large lakes do not actively capture this species because it has no commercial value, and it is not profitable when sold. Moreover, when this species is caught as by-catch, it is usually killed and disposed and/or released into the lakes against the law, instead of being consumed. Processing and making this fish interesting as food, will encourage fishermen to maximize fishing pressure and harvest, helping to counteract population growth. As such, with the help of two social cooperatives and a specialized high school, experimentations will be made on the best processing and cooking techniques, which will be further recorded and assessed by the evaluation teams (WP2). We believe that the associated risk of inducing a further spread of the species in large Italian perialpine lakes is limited due to the cultural and historical economic interests in other fishery resources (i.e., perch, trout and coregonids), which would be very unlikely to be overcome by *S. glanis*. Another potential risk associated with catfish consumption is related to the possible presence of contaminants accumulated in the flesh of the fish (Squadrone et al. 2013; Squadrone et al. 2015). This aspect will not be addressed directly in this project, however, since there is usually a relationship between contaminants concentration and fish length and/or biomass (e.g., Squadrone et al. 2013), as a precaution only individuals smaller than 100 cm in total length will be allocated to human consumption to reduce risks for human health.

Alongside with this, to boost the replication and exploitation of the project results, a Southern European Working Group (SEMG) will be created to constitute a network of stakeholders interested in the management of *S. glanis* invasion, with which the project managers will share and discuss relevant opinions, strategies, and protocols. The SEMG will be formed by different institutions and authorities responsible for environment, fishing, and biodiversity management in northern Italy and Portugal, but also in other regions and countries outside the project area (e.g., central Italy, France, and Spain). Even though the project only includes Italy and Portugal, other countries are also interested in the same issues of increasing expansion and inefficient management of catfish and could thus be interested to share their experiences, exchange knowledge and best practices, and learn from the experiences acquired during this project (e.g. https://stopsiluro.webflow.io – Spanish lead initiative). The SEMG could also constitute a basis for southern European states to improve cooperation as envisaged by Art. 11 of the EU Regulation 1143/2014 concerning species that are native only to some areas in Europe like *S. glanis*.

Moreover, given that the main vector of catfish introduction and spread is translocation acted mainly by anglers, preventive information campaigns will be addressed directly to fishermen and anglers, particularly catfish practitioners. Awareness campaigns directed to anglers will be held throughout the project and will focus on the dissemination of negative impacts of catfish on aquatic biodiversity and fisheries and the consequences of illicit behaviours during fishing.

Finally, to ensure the replicability of the project techniques, specific workshops will be organized for transferring knowledge about catfish capture techniques and use of eDNA in monitoring aquatic IAS, along with the preparation of written guidelines and protocols that will be publicly available.

WP8. Project dissemination and outreach plan

This WP is dedicated to the elaboration of the dissemination materials, including the development of the visual identity, informatic resources, and movies of the project, and to the planning of the dissemination and public outreach of the project aims, methodologies, and results.

To be successful, communication plans of projects such as this should make use of a wide range of available media to actively engage as much people as possible, considering that different media have different audience capability (Davis et al. 2018). Therefore, public outreach will be pursued using multiple available media such as via the creation of a dedicated website (http://lifepredator.eu/) and social media pages (Facebook, Instagram) as well as through press releases, newsletters and networking with other projects. To reach a high number of people and maximize the potential to reach the general public, several permanent and travelling exhibitions will be conducted at public locations. The travelling exhibitions will consist in public meetings and conferences held in the regions where the project activities are foreseen and will be performed by personnel with experience in science communication. Permanent exhibitions will comprise the exposure of printed dissemination materials in strategic public locations (e.g., museums, national parks, shopping centres etc.) in the surroundings of the project area.

Beside public outreach events, the project foresees other dissemination forms, suitable for different audiences. The preparation of specific educational kits will make the project contents available for schools of different levels; participation and exhibition in fishing fairs and specialized press will make the project highly visible to anglers and fishing passionate who do not live in the surroundings of the project area and could not be otherwise actively involved; the presentation in scientific conferences and the production of scientific publications will make the project visible to scientists and technicians; the production of technical guidelines and protocols will make it easier for professionals to reach and exploit the project results.

Conclusions

LIFE PREDATOR is an ambitious, scientifically informed management project based on an integrative and engaging approach oriented towards the design and implementation of control and eradication actions and the evaluation of their effects on biodiversity, ecosystem functioning and services, and towards the development of an early warning system based on eDNA and citizen science. By engaging key stakeholders and providing new ecological and social information on the invasive *S. glanis*, the project promotes long-term effectiveness in the management of the invasion by this alien fish. Moreover, it ensures that lessons learned become available for replication in other southern European aquatic systems prone to *S. glanis* invasion and eventually may be extended to the management of other aquatic IAS.

Acknowledgements

We are particularly thankful to Dr Piero Genovesi and Dr. Raf Bayens for their valuable suggestions and revisions of the manuscript.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

The project is co-funded by the European Commission under the EU LIFE Nature & Biodiversity Project programme (Project 101074458 — LIFE21-NAT-IT-PREDATOR) and has received further economic support by Cariplo Foundation (IT), the Hunting and Fishing Office of Canton Ticino (CH), DG Agricoltura e Sistemi Verdi di Regione Lombardia (IT), Conserveira do Interior, Lda (PT), Município de Vila Velha de Ródão (PT).

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

List of lakes and characteristics

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Data type: xlsx

Explanation note: Characteristics of the 50 lakes and reservoirs targeted by LIFE PREDATOR. Indications of the work packages (WPs) where the lake/reservoir will be specifically involved and a brief list of the foreseen activities are also reported.

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Link: https://doi.org/10.3897/neobiota.93.105200.suppl1